Characterizing X-ray Attenuation of Containerized Cargo

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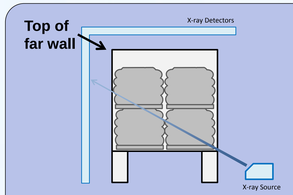
Introduction:

Approximately 20 million cargo containers are imported into the United States every year. The Department of Homeland Security's Domestic Nuclear Detection Office (DNDO) aims to characterize new and emerging technologies to ensure that imported cargo does not contain radiological or nuclear (Rad/Nuc) threats. Previous DNDO studies have shown that detection performance varies with cargo density and complexity.

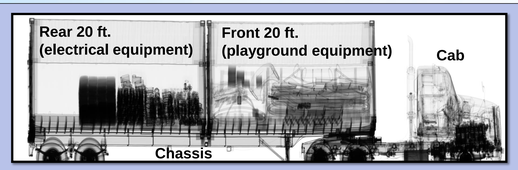
Goals

Our objective was to estimate cargo density from x-ray radiographs taken using a Smiths Detection HCVM scanner. Radiographic images of both engineered cargos and stream-of-commerce (SOC) cargos were used.

Mobile HCVM scanner

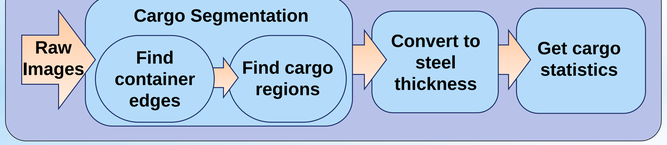


End view of scanning geometry



Sample image of two 20 ft. containers on a truck

Procedure:



Because most containers were not completely filled with cargo, the cargo-containing areas were segmented before further analysis. This was done in two steps: location of the container boundary and thresholding inside this boundary.

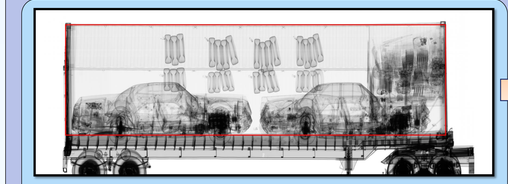
Locating Container Boundaries

- Vertical container walls were located by:
  - Summing columns within regions of interest
  - Identifying threshold crossings in the column sums
- Top of container was located similarly by summing rows
- Container height was fixed
- Container boundaries were written to a file and anomalies were manually corrected (fewer than 5%) prior to subsequent processing

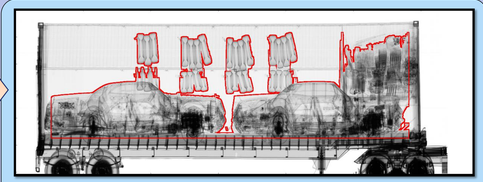
Segmenting Radiographic Images:

Container Boundary Identification by Edge Finding

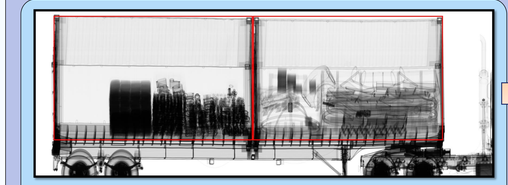
Cargo Segmentation by Thresholding within Container



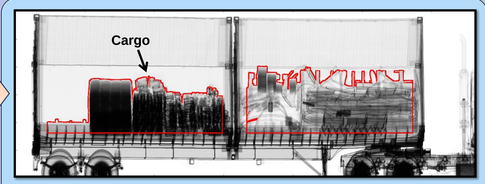
Example 40 ft. container



Example 40 ft. container

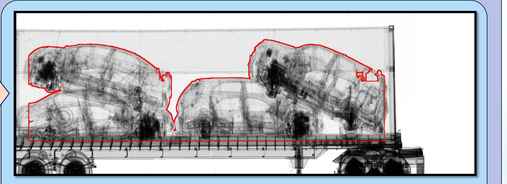


Example 20 ft. containers

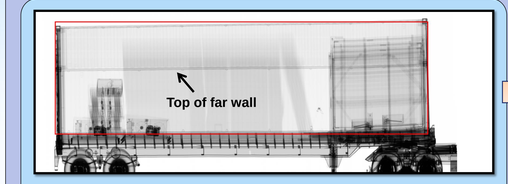


Example 20 ft. containers

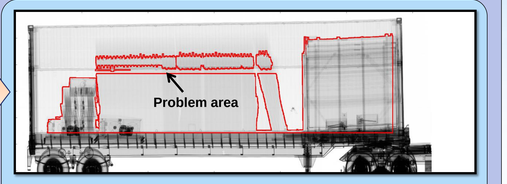
Failure on clipped image



Success after manual correction of container boundary



Extremely low density cargo



Segmentation issue around top of far wall

Segmenting Cargo Regions

- Far wall top edges running through containers were located with a peak-finding algorithm and removed by interpolation

Example of far wall edge removal

- Piecewise thresholds were applied to segment the cargo
- Masked cargo regions were saved for subsequent analysis

Converting to Steel Thickness

The x-ray attenuation (μx) of the cargo was calculated using Beer's Law: $I = I_0 e^{-\mu x}$. Attenuation (μx) was then converted to equivalent steel thickness using a lookup table based on steel plates of known thickness. Equivalent steel thickness was a quantitative measure of cargo properties independent of the x-ray scanner.

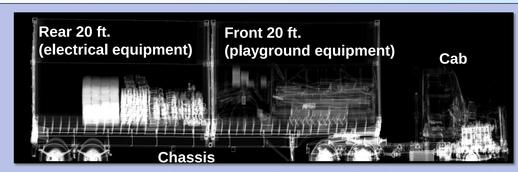
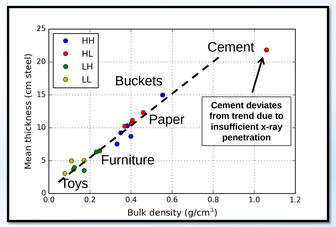


Image converted to equivalent steel thickness units

Results:

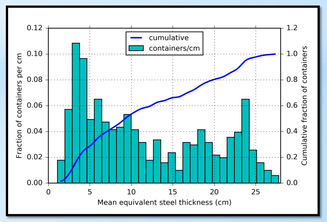


DNDO Engineered Cargos

Mean equivalent steel thickness within masked regions was computed for the 18 engineered cargos. The equivalent steel thickness exhibited a linear correlation with physical bulk density.

SOC Distribution

The distribution of mean equivalent steel thickness for 483 SOC cargos provides an indication of the U.S. import density distribution.



Future Work:

It would be useful to characterize cargo by other metrics, such as inhomogeneity. This work could also be extended to include additional data.

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